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ABSTRACT

This study identified students' conceptual difficulties in understanding concepts and processes associated with cell water relationships (osmosis), determined possible reasons for these difficulties, and pilot-tested instruments and research strategies for a large scale comprehensive study. Research strategies used included content analysis of commonly used textbooks, three paper-pencil questionnaires featuring 72 true/false items, and individual interviews based on two demonstration experiments. One hunderd forty-two students in grades 9, 10, and 11 served as subjects. Among the findings are those indicating that: (1) serious misconceptions exist among high school students and student teachers with regard to basic concepts such as solutions, solubility, particulate nature of matter, and molecular movement, and these misconceptions may well be among the reasons for difficulties in understanding osmosis and osmotic relationships; (2) students use textbook definitions of osmosis and diffusion without fully understanding the concepts; (3) teleology and anthropomorphism are widely used among students, as they provide causal explanations; (4) certain textbooks (such as the Biological Sciences Curriculum Study textbooks) hardly mention osmosis; (5) the terms water potential, osmotic potential, osmotic pressure, and hemolysis are rarely dealt with in high schools; and (6) the research instruments and strategies appear to be adequate and effective. (JN)

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IDENTIFYING STUDENTS DIFFICULTIES IN UNDERSTANDING CONCEPTS PERTAINING TO CELL WATER RELATIONS: AN EXPLORATORY STUDY

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PURPOSE OF STUDY

1. IDENTIFYING STUDENTS DIFFICULTIES IN UNDERSTANDING CONCEPTS PERTAINING TO CELL WATER RELATIONS BY FOCUSING ON OSMOSIS AND RELATED PROCESSES AND STRUCTURES.

2. ATTEMPTING TO FIND OUT THE REASONS FOR CONCEPTUAL DIFFICULTIES AND MISCONCEPTIONS.

3. PILOT TESTING THE INSTRUMENTS AND RESEARCH STRATEGIES AS PREPARATION FOR A LARGE SCALE COMPREHENSIVE STUDY.

PERSPECTIVE

WHY FOCUSING ON OSMOSIS? THERE ARE SEVERAL REASONS:

1. OSMOSIS IS A KEY CONCEPT FOR UNDERSTANDING MANY IMPORTANT LIFE PROCESSES (E.G. WATER INTAKE BY PLANTS, WATER BALANCE IN LAND AND AQUATIC CREATURES, TRANSPORTATION IN LIVING ORGANISMS, ETC.) AND CONSEQUENTLY IT IS STUDIED REPEATEDLY OVER THE SCHOOL YEARS IN A VARIETY OF CONTEXTS.

2. THE CONCEPT OSMOSIS IS CLOSELY RELATED TO KEY CONCEPTS IN PHYSICS AND CHEMISTRY (E.G. DIFFUSION, PERMEABILITY, SOLUTIONS, PARTICULATE NATURE OF MATTER, ETC.).

3. EXPERIENCE HAS SHOWN THAT THE TOPIC IS DIFFICULT, PROBABLY BECAUSE OF THE DEMAND FOR ABSTRACT REASONING AND THE DEPENDENCE OF THE PROCESS ON MANY FACTORS.

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METHOD

THREE DATA SOURCES WERE USED: CONTENT ANALYSIS OF TEXTBOOKS, WRITTEN TESTS AND INDIVIDUAL INTERVIEWS.

1. CONTENT ANALYSIS OF TEXTBOOKS

CONTENT ANALYSIS WAS PERFORMED ON ALL HIGH SCHOOL BIOLOGY TEXTBOOKS USED IN ISRAEL AS WELL AS ON FOUR BOOKS USED IN THE U.S.A. (THREE VERSIONS OF THE BSCS AND KEETON, 1980) AND TWO USED IN THE U.K. (NUFFIELD BOOKS).

THE TEXTBOOKS WERE EXAMINED FOR THE PRESENTATION AND THE WAYS USED TO EXPLAIN CONCEPTS AND PHENOMENA RELATED TO OSMOSIS AND DIFFUSION.

2. WRITTEN TESTS

SEVENTY-TWO TRUE/FALSE ITEMS WERE DESIGNED, SOME BASED ON DIAGRAMS. THE FOLLOWING TOPICS AND CONCEPTS WERE INCLUDED: SOLUTIONS, SOLUBILITY, DIFFUSION, OSMOSIS, PROCESSES RELATED TO OSMOSIS IN PLANTS AND ANIMALS, STRUCTURE AND SIZE OF MOLECULES INVOLVED IN OSMOTIC PROCESSES. SOME OF THE ITEMS WERE ADAPTED FROM ARNOLD AND SIMPSON (1982).*

THE ITEMS WERE RANDOMLY DIVIDED INTO THREE GROUPS, EACH CONSTITUTING A TEST COMPRISED OF 24 ITEMS. ONE THIRD OF THE STUDENTS IN EACH CLASS RESPONDED TO EACH TEST (ADMINISTRATION TIME WAS 15 TO 20 MINUTES). IN THIS WAY A LOT OF INFORMATION WAS GATHERED IN A SHORT TIME.

3. INDIVIDUAL INTERVIEWS

TWO EXPERIMENTS SERVED AS THE BASIS FOR THE INTERVIEWS: ONE REPRESENTING A MODEL (CELLOPHANE BAGS IN SOLUTIONS OF DIFFERENT CONCENTRATIONS) (FIGURE 1A) AND THE OTHER INVOLVING A LIVING SYSTEM (EGG YOLK IN SOLUTIONS OF DIFFERENT CONCENTRATIONS) (FIGURE 1B).

A SEQUENCE OF PREPARED QUESTIONS WAS USED IN THE INTERVIEW. THE INTERVIEWEE HAD, ESSENTIALLY, TO DESCRIBE THE OBSERVED PHENOMENON (OBSERVATION AND INTERPRETATION), TO EXPLAIN WHY THINGS HAPPEN AS THEY HAPPEN (ANALYSIS AND SYNTHESIS) AND TO PREDICT WHAT WILL HAPPEN NEXT, OR UNDER DIFFERENT CONDITIONS (APPLICATION, EXTRAPOLATION). THE INTERVIEWS TOOK PLACE AFTER THE COMPLETION OF THE WRITTEN TESTS.

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*Arnold, B. and Simpson, M. (1982), Concept Development and Diagnostic Testing in Osmosis in "O" Grade Biology, Aberdeen, College of Education.

THE SAMPLE CONSISTED OF STUDENTS FROM TWO SCHOOLS IN JERUSALEM AND WAS DISTRIBUTED AS FOLLOWS: GRADE 9 (N=64), GRADE 10 (N=40), GRADE 11 (N=38). FOR THE INDIVIDUAL INTERVIEWS NINE STUDENTS WERE SELECTED, THREE IN EACH GRADE LEVEL: LOW ACHIEVER, AVERAGE, HIGH ACHIEVER. THE INTERVIEW LASTED 20 TO 30 MINUTES.

IT SHOULD BE MENTIONED THAT ALL THE STUDENTS IN THE SAMPLE STUDIED OSMOSIS IN GRADE 9, WHEN THE TOPIC "THE CELL" IS USUALLY STUDIED IN ISRAELI SCHOOLS.

THE RESULTS OF THE TESTS WERE ANALYZED BY SPSS PROGRAMS WHICH YIELDED MEANS AND STANDARD DEVIATIONS. THE INTERVIEWS WERE TAPE RECORDED, TRANSCRIBED AND ANALYZED ALONG THREE DIMENSIONS NAMELY DESCRIPTION, EXPLANATION AND APPLICATION.

ON THE BASIS OF THE PILOT STUDY THE TESTS WERE REVISED (SEE BELOW) AND ADMINISTERED TO A GROUP Of 16 BIOLOGY STUDENT TEACHERS. THE RESULTS OBTAINED WITH THI GROUP ARE ALSO REPORTED.

RESULTS AND DISCUSSION

ANALYSIS OF TEXTBOOKS

CERTAIN KEY CONCEPTS ARE NOT DISCUSSED AT ALL IN CERTAIN TEXTBOOKS. FOR EXAMPLE, ALL THREE VERSIONS OF THE BSCS HARDLY MENTION OSMOSIS AND REFER TO IT AS DIFFUSION THROUGH A MEMBRANE. RELATED CONCEPTS SUCH AS OSMOTIC PRESSURE OR POTENTIAL ARE ABSENT AS WELL. SOMETIMES DIFFERENT TERMINOLOGY IS USED FOR THE SAME OBJECT (E.G. SELECTIVELY, PERMEABLE, SEMIPERMEABLE, DIFFERENTLY PERMEABLE), A PRACTICE WHICH MAY BE CONFUSING. CERTAIN TEXTBOOK PRESENTATIONS MAY BE MISLEADING, FOR EXAMPLE THE STATEMENT "DIFFUSION ENDS WHEN EQUAL CONCENTRATIONS ARE REACHED" CERTAINLY DOES NOT APPLY TO MANY OSMOTIC SYSTEMS.

TEST RESULTS

IN ALL THREE TESTS THERE WERE NO DIFFERENCES BETWEEN THE TWO SCHOOLS. THERE WERE ALSO NO DIFFERENCES BETWEEN THE GRADE LEVELS EVEN THOUGH THE TOPIC WAS STUDIED IN GRADE 9. THE ONLY STATISTICALLY SIGNIFICANT DIFFERENCE FOUND WAS BETWEEN THE TESTS: THE RESULTS OF TESTS 1 AND 2 WERE DIFFERENT FROM THOSE OF TEST 3 (SEE TABLE 1).

EXAMINATION OF THE ITEMS IN THE THREE TESTS SUGGESTS THAT THE REASON FOR THE RELATIVELY LOW PERFORMANCE IN TEST 3 WAS THE HIGH PROPORTION OF QUESTIONS WHICH REQUIRED KNOWLEDGE OF CHEMICAL CONCEPTS (E.G. SOLUTIONS, SOLUBILITY), WHICH APPARENTLY ARE DIF-

FICULT, PERHAPS BECAUSE OF BEING UNFAMILIAR TO BIOLOGY STUDENTS IN ALL THREE GRADE LEVELS.

THERE WERE CERTAIN ITEMS IN WHICH STUDENTS HAVE REACHED MASTERY. FOR EXAMPLE:

ALL PLANT CELLS HAVE MEMBRANE AND CELL WALL (82% CORRECT).

A SELECTIVE MEMBRANE PERMITS THE PASSAGE OF SOME SOLUTES (96%).

HOWEVER, IN MANY ITEMS SERIOUS DIFFICULTIES WERE FOUND. FOR EXAMPLE:

THE SPACES BETWEEN WATER MOLECULES CONTAIN NOTHING (27% CORRECT).

THE MOLECULES OF A DISSOLVED SUBSTANCE ARE RANDOMLY DISTRIBUTED IN THE SOLUTION (32% CORRECT).

SPECIAL DIFFICULTIES WERE FOUND WITH REGARD TO OSMOTIC PROCESSES IN LIVING ORGANISMS, AND TO THE CONCEPTS "SOLUBILITY," "OSMOTIC PRESSURE," "OSMOTIC POTENTIAL" AND "WATER POTENTIAL."

RESULTS OF INTERVIEWS

THE RESULTS OF THE INTERVIEWS SUPPORT THOSE OBTAINED FROM THE WRITTEN RESPONSES BUT, AS EXPECTED, ADD INTERESTING INFORMATION.

ALL THE INTERVIEWEES WERE CAPABLE OF DESCRIBING THE OBSERVED PHENOMENA. HOWEVER, SEVERAL USED NON-SCIENTIFIC TERMINOLOGY - FOR EXAMPLE " THE EGG YOLK RELEASED WATER." THE DIFFERENCE BETWEEN DIFFUSION AND OSMOSIS WAS NOT CLEAR. SEVERAL STUDENTS INSISTED THAT "DIFFUSION INVOLVES THE MOVEMENT OF THE SOLUTE" WHILE "OSMOSIS INVOLVED THE MOVEMENT OF THE SOLVENT." TELEOLOGY AND ANTHROPOMORPHISM APPEARED QUITE OFTEN IN THE EXPLANATIONS. FOR EXAMPLE: "THE WATER MOVES OUT IN ORDER TO BALANCE THE CONCENTRATIONS," OR "THE MEMBRANE LETS IN SUBSTANCES WHICH ARE NEEDED BY THE CELL." AS TO PREDICTIONS MOST STUDENTS INSISTED THAT THE MOVEMENT WILL STOP WHEN EQUAL CONCENTRATIONS WILL BE REACHED. THIS CLAIM WAS PUT FORWARD EVEN IN SYSTEMS WHICH HAD DISTILLED WATER ON ONE SIDE SO THAT IT SHOULD HAVE BEEN OBVIOUS THAT EQUAL CONCENTRATIONS COULD NEVER BE REACHED. NEVERTHELESS MOST STUDENTS DID PREDICT CORRECTLY THAT THE EGG YOLK, IF KEPT IN DISTILLED WATER, WILL EVENTUALLY BURST WHILE A PLANT CELL WILL NOT BURST SINCE IT HAS A CELL WALL.

DURING THE INTERVIEWS WE FOUND THAT STUDENTS KNEW RATHER LITTLE ABOUT TOPICS RELATED TO CHEMISTRY SUCH AS SOLUTIONS AND CONCENTRATIONS. FOR EXAMPLE: "WHEN SUGAR DISSOLVES IT BREAKS INTO SMALL MOLECULES," OR "IT DOES NOT MATTER HOW MUCH WATER GETS OUT - AS LONG AS THE QUANTITY OF SUGAR INSIDE DOES NOT CHANGE THE CONCENTRATION REMAINS CONSTANT." THESE FINDINGS ARE SIMILAR TO THOSE REPORTED EARLIER REGARDING THE RESULTS OF THE WRITTEN TESTS.

REVISION OF TESTS

ON THE BASIS OF THE PILOT STUDY WE MADE SOME IMPROVEMENTS IN THE RESEARCH INSTRUMENTS:

A. WE ELIMINATED FROM THE TESTS THE ITEMS DEALING WITH THE CONCEPTS OSMOTIC POTENTIAL AND WATER POTENTIAL AS IT WAS OBVIOUS THAT THESE CONCEPTS WERE NOT USED IN ISRAELI HIGH SCHOOLS. THE REMAINING ITEMS WERE INCORPORATED IN TWO TESTS EACH CONSISTING OF 30 ITEMS COVERING THE SAME AREAS AS THE THREE ORIGINAL TESTS.

B. WE ADDED 2 NEW SECTIONS TO EACH TEST: IN SECTION ONE THE STUDENTS HAVE TO DEFINE THE CONCEPTS OSMOSIS AND DIFFUSION IN THEIR OWN WORDS. SECTION TWO PRESENTS A LIST OF 10 CONCEPTS (5 OF THESE APPEARED IN BOTH TESTS) LIKE: OSMOTIC PRESSURE; PLASMOLISIS; SEMIPERMIABLE MEMBRANE. THE STUDENTS WERE ASKED TO STATE ON 2 POINTS SCALE WHETHER THEY STUDIED EACH OF THESE CONCEPTS PREVIOUSLY, AND ON 5 POINTS SCALE THEIR OWN ASSESSMENT OF THEIR UNDERSTANDING OF EACH CONCEPT WHEN 1 = DO NOT UNDERSTAND AND 5 = UNDERSTAND AND CAN EXPLAIN TO OTHERS.

RESPONSES OF STUDENT TEACHERS

AS WE SUSPECTED THAT SOME OF THE DIFFICULTIES REPORTED ABOVE MAY STEM FROM THE TEACHERS, WE ADMINISTERED THE NEW VERSIONS OF THE TESTS TO A GROUP OF BIOLOGY STUDENT TEACHERS (N=16).

THIS TIME THERE WAS NO STATISTICAL DIFFERENCE BETWEEN THE RESULTS OF THE TWO TESTS $\bar{X}_1$ = 21.12 (OUT OF 30), S.D. = 2.85; $\bar{X}_2$ = 21.75, S.D. = 2.71) THE MAIN DIFFICULTIES EXHIBITED BY THE HIGH SCHOOL STUDENTS, WERE ALSO FOUND AMONG THE STUDENT TEACHERS:

1. ITEMS RELATED TO CHEMISTRY AND THE OSMOTIC PRESSURE WERE FOUND TO BE QUITE DIFFICULT.

2. EVEN THOUGH THE STUDENT TEACHERS MENTIONED THAT THEY STUDIED ALL THE 10 CONCEPTS, AND HIGHLY ESTIMATED THEIR LEVEL OF UNDERSTANDING OF THESE CONCEPTS ($\bar{X}$ = 4.23 (OUT OF 5), S.D. = 0.88), THEIR DEFINITIONS OF THE TWO MAJOR CONCEPTS NAMELY OSMOSIS AND DIFFUSION WERE VERY POOR: MOST OF THEM INCLUDED JUST TWO COMPONENTS OUT OF THE THREE (NAMELY: WATER, CONCENTRATION DIFFERENCE AND SEMIPERMIABLE MEMBRANE) REQUIRED FOR THE DEFINITION OF OSMOSIS AND MANY MISTAKENLY IDENTIFIED CONCENTRATION DIFFERENCE AS THE CAUSE OF DIFFUSION.

CONCLUSIONS

1. THE RESEARCH INSTRUMENTS AND STRATEGIES APPEAR TO BE ADEQUATE AND EFFECTIVE. RESULTS OBTAINED WITH THE PHYSICAL MODEL WERE SIMILAR TO THOSE OBTAINED WITH THE LIVING SYSTEM.

2. SERIOUS MISCONCEPTIONS EXIST AMONG HIGH SCHOOL STUDENTS AND STUDENT TEACHERS WITH REGARD TO BASIC CONCEPTS SUCH AS SOLUTIONS, SOLUBILITY, PARTICULATE NATURE OF MATTER, MOLECULAR MOVEMENT. THESE MISCONCEPTIONS MAY WELL BE AMONG THE REASONS FOR DIFFICULTIES IN UNDERSTANDING OSMOSIS AND OSMOTIC RELATIONS.

3. STUDENTS USE TEXTBOOK DEFINITIONS OF OSMOSIS AND DIFFUSION WITHOUT FULLY UNDERSTANDING THE CONCEPTS.

4. TELEOLOGY AND ANTHROPOMORPHISM ARE WIDELY USED AMONG HIGH SCHOOL STUDENTS, AS IF THEY PROVIDE CAUSAL EXPLANATIONS.

5. THE TERMS WATER POTENTIAL, OSMOTIC POTENTIAL, OSMOTIC PRESSURE AND HEMOLYSIS ARE RARELY DEALT WITH IN HIGH SCHOOLS.

TABLE I

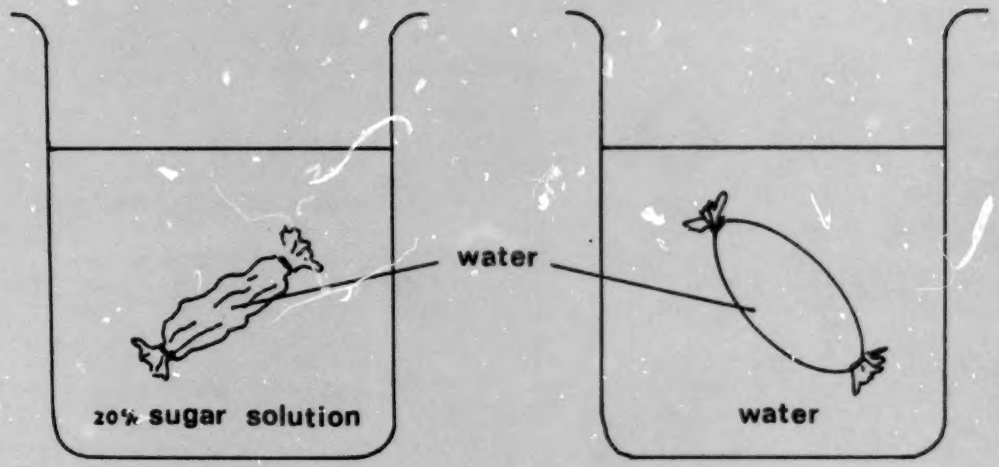
RESULTS OF THE THREE TESTS

TEST 1			TEST 2			TEST 3			
N	$\bar{X}$	S.D.	N	$\bar{X}$	S.D.	N	$\bar{X}$	S.D.	F
48	14.94	4.12	44	15.82	2.62	50	12.86	29.30	10.15*

In each test the highest possible score was 24

*P< 0.001

Figure 1: Experiments representing osmosis



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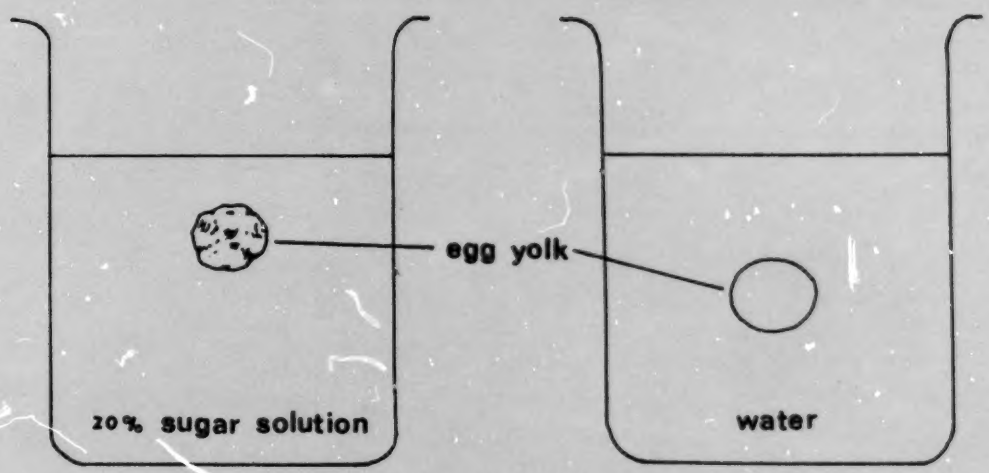

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